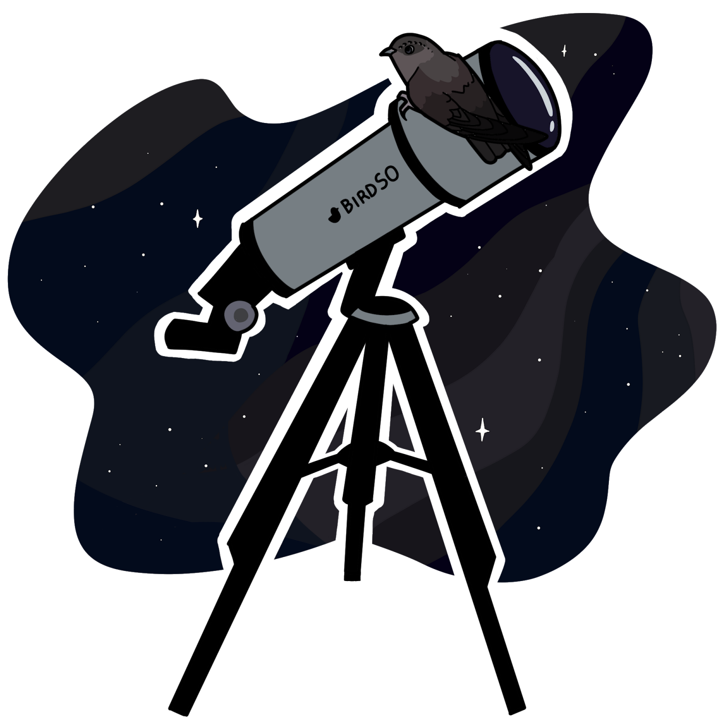
Astronomy C

BIRDSO Invitational



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Part 1 of this test will concern DSOs and general Astronomy knowledge. Part 2 will involve more calculations, and more fun… maybe?

(Source: Charlotte)

Good luck! (And if you could do me a favor, please don't put troll answers to questions you don't know! I can't stop you, but please don't! It would save me a great deal of time and sanity. Thanks, and enjoy the ride!)

Part 1: Obligatory DSO / Gen. Knowledge (40 points)

Some questions in this section will refer to the image sheet.

Questions 1-10 refer to the deep sky object H1821+643.

1. [1] Which image shows H1821+643?
2. [1] H1821+643 is classified as a *quasar*, which is a type of active galactic nucleus. Which of the following is NOT true of AGNs?

    a. Quasars are powered by matter falling into their central supermassive black holes
    b. Quasars are usually radio-quiet, while Seyfert galaxies are usually radio-loud
    c. Quasars are distinct from Seyfert galaxies in that the central SMBH usually outshines the entire galaxy
    d. Quasars are more common in the early universe than today
3. [1] Recently, Chandra spectra measurements of H1821+643 has been used to provide evidence for WHIM. What does WHIM stand for?
4. [1] Which absorption line was detected in the spectrum of H1821+643 that is thought to have originated from intervening WHIM?
5. [3] Normally, absorption line from a single filament of WHIM would be far too weak to detect. However, these astronomers used a clever method: they stacked the spectra from multiple intervening filaments of WHIM by blueshifting them back to their rest wavelength. But how did they know what the redshift of each filament was?
6. [1] Name the image that corresponds to the above method.
7. [1] WHIM is thought to be the solution to the missing baryon problem, which is that ___ % of baryonic matter in the low-z universe is unaccounted for.
    a. 5
    b. 10
    c. 20
    d. 30
8. [1] About what percentage of the mass-energy content of our universe is baryonic matter?
    a. 5%
    b. 10%
    c. 25%
    d. 75%
9. [2] In 2020, the results of the first direct detection of WHIM emission was announced; the same stacking method to amplify signals was utilized. What kind of signal did they detect?
    a. UV emission

b. X-ray emission
c. UV absorption lines
d. X-ray absorption lines

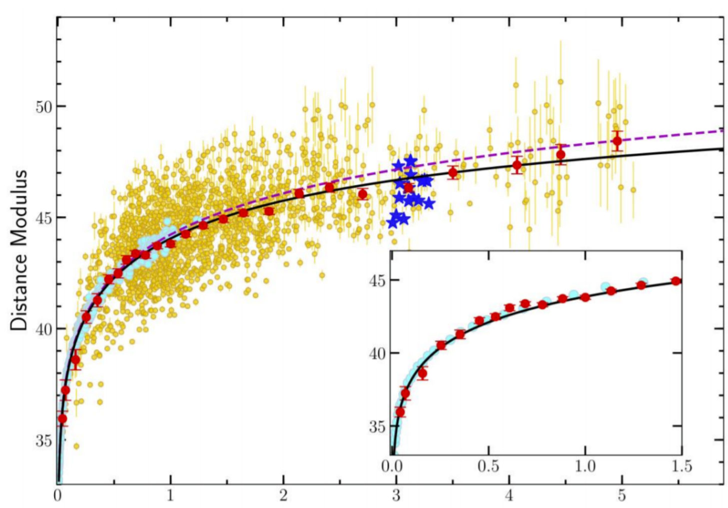
10. [2] These astronomers found an average gas temperature of 0.9 keV in filament-core regions of WHIM. What temperature does this correspond to?
    a. 10^4 K
    b. 10^5 K
    c. 10^6 K
    d. 10^7 K

Questions 11-21 refer to a recent paper that finds the possibility of the density of dark energy varying over time.

11. [1] This discovery used data from 1,598 quasars. Two of them are in our event rules; name these two quasars.
12. [1] Name the image corresponding to these two quasars.
13. [1] The researchers found evidence supporting the idea that the density of dark energy was
    a. Increasing over time
    b. Decreasing over time
    c. Increasing, then decreasing over time
    d. Decreasing, then increasing over time
14. [2] To estimate distances to these quasars, the researchers used a novel correlation between UV and X-ray luminosity. From Chandra's press release: "Some of the UV photons collide with electrons in a cloud of hot gas...above and below the disk, and these collisions can boost the energy of the UV light up to X-ray energies. This interaction causes a correlation between the amounts of observed UV and X-ray radiation. This correlation depends on the luminosity of the quasar". This interaction between UV photons and electrons is called what?
15. [1] There are many different distance measures in astronomy. Distance modulus is equivalent to which type of distance measure?

a. Proper distance
b. Comoving distance
c. Luminosity distance
d. Angular diameter distance
e. Geass distance

16. [1] Meanwhile, the distance in Hubble's law $v = H_0 d$ gives which kind of distance?
    a. Proper distance
    b. Comoving distance
    c. Luminosity distance
    d. Angular diameter distance
    e. Geass distance
17. [1] These two types of distances are distinct; thus, how distance modulus depends on an object's redshift is dependent on the details of the expansion of the universe, as different models of the universe predict different relationships. A plot of distance modulus vs redshift is called a *Hubble diagram*. The Hubble diagram from this paper is shown below: the purple dashed line is the ΛCDM model, while the black line is the best fit of the data.



    We can see that there is a deviation from the ΛCDM model at
    a. Lower redshifts
    b. Higher redshifts
18. [2] In the ΛCDM model, the density of dark energy

a. Increases over time
b. Decreases over time
c. Stays the same over time

19. [2] In the ΛCDM model, the density of dark matter
    a. Increases over time
    b. Decreases over time
    c. Stays the same over time
20. [1] At these redshifts, quasars were moving faster/slower away from us than expected for the ΛCDM model for a given distance modulus. Thus, the universe was expanding faster/slower than expected in the past.
    a. Faster, faster
    b. Faster, slower
    c. Slower, faster
    d. Slower, slower
21. [2] Plotting Hubble diagrams has long been useful for investigating which model best suits our universe. For example, doing the same to type 1a supernova data in 1999 supported the existence of what?
    a. Dark matter
    b. A cosmological constant
    c. Antimatter
    d. The Big Bang

Questions 22-29 refer to Image A on the image sheet.

22. [1] The Hubble Space Telescope took this image as part of which survey?
23. [2] In which region (as labelled on the image) was SN UDS10Wil found?
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
    f. 6
24. [1] What type of supernova was SN UDS10Wil?

a. Ia
b. Ib
c. Ic
d. IIb
e. II-L
f. II-P

25.[1] SN UDS10Wil is among the most distant supernovae detected to date. When SN UDS10Wil occurred, the universe was approximately what fraction of its size today? (More precisely, distances back then were what fraction of the corresponding distance today?)

a. 1/2
b. 1/3
c. 1/4
d. 1/5

26.[2] Using its redshift z=1.914, calculate SN UDS10Wil's recessional velocity in km/s.

a. $1.3 * 10^5$ km/s
b. $2.4 * 10^5$ km/s
c. $3.5 * 10^5$ km/s
d. $4.6 * 10^5$ km/s
e. $5.7 * 10^5$ km/s

27.[1] Use Hubble's law to calculate the distance to UDS10Wil in Gpc. Use H_0=70 km/s/Mpc.

a. 3 Gpc
b. 8 Gpc
c. 12 Gpc
d. 3000 Gpc
e. 8000 Gpc

28.[2] UDS10Wil had a peak apparent magnitude of 26.15. Assuming that this type of supernova has a peak absolute magnitude of -19.3, what's the distance in Mpc to SN UDS10Wil using a distance modulus calculation?

a. 3 Gpc
b. 8 Gpc

c. 12 Gpc
d. 3000 Gpc
e. 8000 Gpc

29.[1] Are these distances the same? Do you expect them to be the same?

a. Yes, yes
b. No, no
c. Yes, no
d. No, yes

Part 2: Calculations and ~fun~ (70 points)

In the 2015 anime *Charlotte*, the short-period comet named Charlotte passes near the Earth every 75 years. During its approach, the comet spreads a kind of virus on the Earth that can trigger supernatural abilities in preadolescent children.

30. [1] What is the semi-major axis of comet Charlotte's orbit?
    a. 8.9 AU
    b. 17.8 AU
    c. 26.7 AU
    d. 35.4 AU
31. [1] The minimum possible perihelion of comet Charlotte is around 0.2 AU (any closer and it could break up due to passing too close to the sun). What is the maximum possible aphelion of comet Charlotte?
    a. 17.8 AU
    b. 26.7 AU
    c. 35.4 AU
    d. 46.6 AU

32.[1] What is the corresponding eccentricity?

a. 0.011
b. 1.011
c. 0.573
d. 0.988
e. 1.988

33.[3] Assuming a perihelion of 0.2 AU, what is comet Charlotte's orbital velocity at perihelion? Use the Vis-Viva equation, which is $v^2 = GM(\frac{2}{r} - \frac{1}{a})$, where *r* is the orbital distance, *a* is the semi-major axis, and *v* is the orbital velocity at that distance. (Notice that in the case of circular motion where *r=a*, the equation becomes the familiar $v^2 = GM/r$.)

a. 9.4 km/s
b. 10.5 km/s
c. 11.6 km/s
d. 12.7 km/s

One character that I made up--let's call her Robette--obtained the power to manipulate gravity. However, since Robette could not control the ability well, she accidentally changed the universal law of gravity from an inverse-squared law to an inverse-cubed law (i.e. gravity is now governed by $F = G'Mm/r^3$ instead of $F = GMm/r^2$, where *G'* is a new constant of gravity). Miraculously, Earth's orbit still stayed the same.

34.[3] What is the value of the constant *G'* in SI units? (Give both the value and units).

a. $4.46 * 10^{-22}$ m^2 kg^{-1} s^{-2}
b. $6.67 * 10^{-11}$ m^3 kg^{-1} s^{-2}
c. 9.98 m^4 kg^{-1} s^{-2}
d. 44.6 m^4 kg^{-1} s^{-2}

35.[1] True or False: The force of gravity on Mercury from the sun would become greater than it was before.

36.[1] True or False: The force of gravity on Jupiter from the sun would be greater than it was before.

37.[1] What would happen to Mercury after gravity was suddenly changed?

a. It would fall towards the sun into a closer orbit
b. It would stay in the same orbit
c. It would veer into an orbit farther from the sun

38.[1] What would happen to Jupiter after gravity was suddenly changed?

a. It would fall towards the sun into a closer orbit
b. It would stay in the same orbit
c. It would veer into an orbit farther from the sun

39.[2] True or False: Kepler's 1st law would still be valid after this change.

40.[2] True or False: Kepler's 2nd law would still be valid after this change.

Kepler's 3rd law is difficult to derive for a general orbit, but is quite easy to derive for a circular orbit: simply set the gravitational force equal to the centripetal force $F_c = mv^2/r$. Substituting in $v = 2\pi r/T$ (where T is the time it takes for the planet to orbit one revolution) and solving for T would yield Kepler's 3rd law.

41. [2] Find an expression for circular orbital velocity under the new inverse-cubed gravitational law.

a. $v = \sqrt{G'M/r}$
b. $v = \sqrt[3]{G'M/r}$
c. $v = \sqrt{G'M}/r$
d. $v = \sqrt[3]{G'M}/r$

42.[2] Find Kepler's 3rd law for circular orbits under the new inverse-cubed gravitational law.

a. $T^2 = \frac{4\pi^2 r^3}{G'M}$
b. $T^2 = \frac{4\pi^2 r^4}{G'M}$
c. $T^3 = \frac{8\pi^3 r^4}{G'M}$
d. $T^3 = \frac{8\pi^3 r^5}{G'M}$

Satoru Gojo is known as the strongest Jujutsu sorcerer in the world of *Jujutsu Kaisen*. He wears a blindfold, and his brilliant blue high-budget eyes were revealed in Episode 7, when he cast his special technique *Domain Expansion: Infinite Void*.

If I were an elementary school fangirl, I might say something like, *he has eyes that sparkle like stars…* What if his eyes were actually stars? Let us model a blue-white A0-type star the size of the iris (R ~ 6 mm). We will call this star Gojo's Eye.

43.[2] Estimate the temperature of Gojo's Eye in Kelvins.
   a. 3,000 K
   b. 6,000 K
   c. 10,000 K
   d. 30,000 K

44.[2] Estimate the luminosity of Gojo's Eye in Watts.
   a. $1.2 * 10^4$ W
   b. $3.3 * 10^4$ W
   c. $2.6 * 10^5$ W

d. $2.1 * 10^7$ W

45.[2] Let's say you're having a conversation with Satoru Gojo, who is standing 2 meters away. Suddenly, he raises his blindfold, revealing one eye. How many times brighter than the sun will Gojo's Eye appear to be? The solar constant is 1361 W/m^2.

a. 3.7 times brighter
b. 4.8 times brighter
c. 5.5 times brighter
d. 9.3 times brighter

46.[2] Calculate the apparent magnitude of Gojo's Eye from this distance, given that the apparent magnitude of the sun is -26.74.

a. -1.44
b. -10.4
c. -28.2
d. -31.7

47.[2] Let's say that this star is in hydrostatic equilibrium and fuses hydrogen in its core. Roughly estimate its mass (in kilograms) by extrapolating from the mass-luminosity relation for main sequence stars:

$$\frac{L}{L_\odot} \approx 0.23\left(\frac{M}{M_\odot}\right)^{2.3}$$

a. $2.3 * 10^{21}$ kg
b. $8.4 * 10^{24}$ kg
c. $4.2 * 10^{27}$ kg
d. $6.7 * 10^{30}$ kg

48.[3] How many times denser is Gojo's star than a typical neutron star?

a. 10^6
b. 10^7
c. 10^8
d. 10^9
e. 10^{10}

49.[2] Calculate the Schwarzschild radius for Gojo's star. Is this larger or smaller than its radius of 6 mm?

a. 2.8 μm, smaller

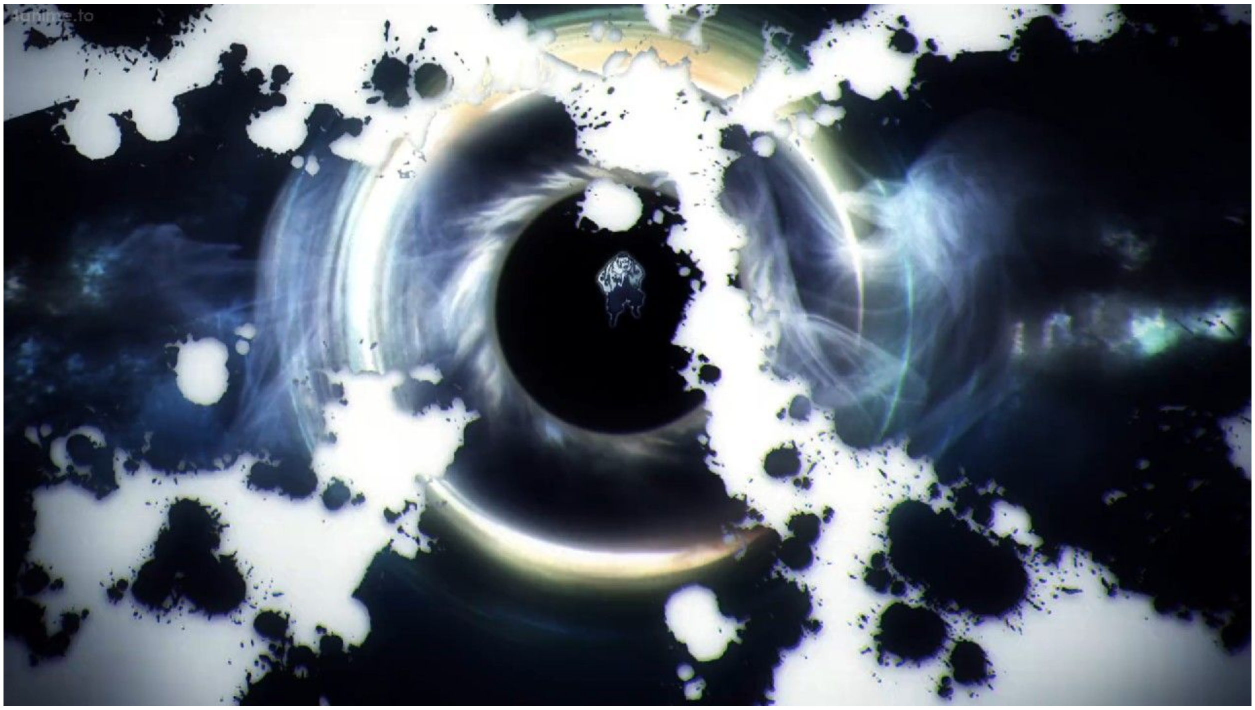
b. 3.4 μm, smaller
c. 6.2 mm, larger
d. 13.3 mm, larger

50.[1] Would Gojo's star collapse into a black hole?

a. Yes
b. No

Next, let's explore Satoru Gojo's special move, *Domain Expansion: Infinite Void*. He creates a domain that quickly expands outward. Inside the domain, there is nothing but a void. Let's treat it as an expanding universe filled with only vacuum energy. (Vacuum energy, as you might imagine, is the energy of the vacuum, which is suggested by quantum mechanics to be nonzero. A nonzero vacuum energy is the simplest explanation for dark energy.) The following equation is the **Friedmann equation**, which models the expansion (given by the Hubble parameter H) of a homogeneous isotropic universe with curvature k filled with a mass density ρ_m and a cosmological constant Λ that represents vacuum energy. The quantity a is the called the scale factor, which represents the relative size of the universe.

$$H^2 = \frac{8\pi G}{3}\rho_m - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$



Gojo's Domain Expansion: Infinite Void, as visualized by the anime.

51. [3] The SI unit of the cosmological constant can be expressed as $m^a\, kg^b\, s^c$. What are a, b, and c?
52. [1] After he defeats his enemy, his domain (mini-universe) shatters, and they are returned to the outside world. Thus, while his domain looked limitless, it was actually finite. What is the geometry of Gojo's mini-universe?
    a. Open ($k < 0$)
    b. Closed ($k > 0$)
    c. Flat ($k = 0$)
53. [3] A simpler way to rewrite the Friedmann equation is to represent curvature and dark energy as densities:

$$H^2 = \frac{8\pi G}{3}(\rho_m + \rho_k + \rho_\Lambda)$$

Solve for an expression for the density ρ_Λ of the vacuum energy in terms of the cosmological constant.

54.[4] What is the minimum possible cosmological constant required for Gojo's universe to expand at the same rate our universe is expanding, 70 km/s/Mpc? The answer choices are in SI units. Use the Friedmann equation.

a. $1.6 * 10^{-13}$
b. $1.31 * 10^{-26}$
c. $7.6 * 10^{-35}$
d. $1.7 * 10^{-52}$

55.[3] What is the corresponding vacuum **energy density** u_Λ?

a. $9.2 * 10^{-27}$ J/m^3
b. $8.3 * 10^{-10}$ J/m^3
c. $8.7 * 10^{12}$ J/m^3
d. $7.9 * 10^{29}$ J/m^3

56.[5] Assuming that $k \approx 0$, the expansion of Gojo's domain is

a. Linear
b. Quadratic
c. Cubic
d. Exponential

Finally, let's look at one more cursed technique of Satoru Gojo: *Hollow Purple*. This technique involves using his *Cursed Technique Amplification: Blue* and *Cursed Technique Reversal: Red*, which each generates a large blue sphere and a large red orb, respectively. Gojo then collides the orbs to produce an enormous purple blast of energy.

It has been suggested by fans that *Cursed Technique Amplification: Blue* and *Cursed Technique Reversal: Red* are based on the concepts of blueshift and redshift. Let's say the two orbs are two white dwarfs, each with temperature 5300 K and radius 1 $R_\oplus$.

57. [2] What is the luminosity of one of these orbs in solar luminosities?
    a. $5.8 * 10^{-7} L_\odot$
    b. $6.0 * 10^{-5} L_\odot$
    c. $2.3 * 10^{-2} L_\odot$
    d. $2.3 * 10^{22} L_\odot$
58. [1] What is the characteristic (peak) wavelength emitted by one of these orbs?
    a. 410 nm
    b. 550 nm
    c. 670 nm
    d. 750 nm
59. [1] At rest, what color would these orbs be?
    a. Red
    b. Orange
    c. Yellow-White

d. Blue-White

60. [1] After generating the two white-dwarf orbs, Satoru Gojo gives the two a very high radial velocity. The orb that appears red is moving ________ the camera, while the orb that appears blue is moving ________ the camera.

a. Towards, towards
b. Towards, away from
c. Away from, towards
d. Away from, away from

61. [1] Let's say that the blue orb appears to emit primarily at 400 nm. What is the redshift *z*?

a. 0.23
b. 0.27
c. 0.33
d. 0.37
e. 0.52

62. [2] What fraction of the speed of light is it traveling at?

a. 0.23
b. 0.27
c. 0.33
d. 0.37
e. 0.52

63. [1] What kind of event would occur after these two stars collide?

64. [2] Assume that this event has an absolute magnitude of -19. How many Joules of energy are released in a millisecond?

65. [2] The gravitational binding energy of a uniform sphere is given by $U = -\frac{3}{5}\frac{GM^2}{R}$. What is the gravitational binding energy of the Earth in Joules?

66. [1] Would Satoru Gojo be able to destroy the Earth in a millisecond?

a. Yes
b. No

Man…

Thanks for taking my Astronomy test! Good luck in the rest of the tournament. For any astronomy-related questions, feel free to shoot me an email at aqc@mit.edu. (And for my favorite animes, see anilist.co/user/stellarevolution.)